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Quarterly Technical Progress Report

IMPROVED EFFICIENCY OF MISCIBLE CO_2 FLOODS AND ENHANCED PROSPECTS FOR CO_2 FLOODING HETEROGENEOUS RESERVOIRS

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US/DOE Patent Clearance is not required prior to the publication of this document.

OBJECTIVE

The objective of this experimental research is to improve the effectiveness of CO_2 flooding in heterogeneous reservoirs. Activities are being conducted in three closely related areas: 1) further exploration of the applicability of selective mobility reduction (SMR) in the use of foam flooding, 2) possible higher economic viability of floods at slightly reduced CO_2 injection pressures, and 3) taking advantage of gravitational forces during low IFT, CO_2 flooding in tight, vertically fractured reservoirs.

SUMMARY OF PROGRESS

Progress made this quarter in each of the three areas of the project is discussed below.

TASK 1 - CO_2-FOAMS FOR SELECTIVE MOBILITY REDUCTION

The objective of Task 1 is the development of selective mobility reduction (SMR) in CO_2-foam flow, enabling field engineers to increase production efficiency in CO_2 flooding of oil reservoirs. This effect, by which the mobility of CO_2 foam in high permeability cores is approximately the same as that in low permeability cores, is observed with some surfactants. Before field engineers can consider using SMR, it is necessary to demonstrate that the effects observed in the laboratory in individual cores of uniform permeability can be used in heterogeneous media to reduce the non-uniform flow of displacing CO_2-foam.

Building on our previous tests in individual cores, we need to perform new types of experiments in which both high and low permeability regions are present. These two sections of a flow system, or core, must also be in capillary contact, as are different portions of a heterogeneous reservoir. We will measure the ratio of mobilities between the two sections during the flow of simple fluids, as well as CO_2-foam, through these cores. The experimental need can be met by two types of tests in which well-defined high and low permeability regions are arranged differently in the flow system.

One type of experiment satisfying the above criterion involves cores in which high and low permeabilities are in parallel. The core is cut from a rock containing two regions, so that the plane separating the two will include the diameter of the core. End-to-end flow through the two sections of the core can then be made to measure the two mobilities. Our search for such parallel heterogeneity cores has not yet produced any candidate cores from reservoirs; although, we have two samples of quarried rock that meet this standard. One of these is a core we cut from a large San Andres outcrop sample (contributed by Texaco), but it exhibits such a large permeability ratio that the experiment we contemplate would take unduly long. A second choice would come from a block of Berea rock (on hand for another project) with greater-than-usual permeability heterogeneities. We expect to be able to cut a core from this block with a permeability ratio of 4 or 5, which will be more suitable for our tests.

Another experiment of this type is being performed with the two sections coaxial. A 1.5 inch diameter Berea core has an axially located, 0.5 inch hole filled with fine unconsolidated sand. The pressure drop along the two sections is the same since they are in parallel, and again, the mobilities can be measured by observing the flows from the two regions separately. To properly perform this type of experiment, two back-pressure regulators are used; one is for the output fluids from each section of the core system. A schematic of the overall flow arrangement for this type of parallel experiment, which is at this time being used for the coaxial flow described above, is shown in Figure 1.

A second type of experiment involves a core with the different permeability sections in series, so the flow rate will be the same through both sections. In this case, mobility measurements can be made by measuring the two pressure drops across each section. This experiment is similar to the series arrangement, with two separate cores in their own coreholders. In the new arrangement the two sections will be in the same coreholder—either being sections of the same rock or being separate cores—tightly butted together with a filter membrane for good capillary contact between them. Such an experiment is also in progress.

TASK 2 - REDUCTION OF THE AMOUNT OF CO_2 REQUIRED IN CO_2 FLOODING

Experimental Tests

Paper SPE 28974 "Dynamic Phase Composition, Density, and Viscosity Measurements During CO_2 Displacement of Reservoir Oil" was completed and will be presented at the SPE International Symposium on Oilfield Chemistry to be held in San Antonio February 14-17, 1995. This worked compares the results of phase equilibrium changes during the injection of pure and impure CO_2 into reservoir crude at pressures both below and above the minimum miscibility pressure.

An abstract, "The Effect of Pressure on CO_2 Oilflood Recovery," written jointly by Duane Gregory (Conoco Inc.) and Reid Grigg (PRRC) was submitted for the SPE Fall Meeting in Dallas. The paper will cover CO_2 corefloods done at Conoco, which will be compared to corefloods reported in the literature. The different tests have produced conflicting results on whether production during tests at pressures near miscible conditions would result in significantly lower recovery compared to pressures well into the miscible region. Early indications are that the crude samples and testing procedures significantly affect the results.

Simulation and Modelling

During this quarter, our focus has been on the implementation of a horizontal well model into MASTER (DOE's pseudo-miscible reservoir simulator). In the original MASTER code, only the vertical well parallel to the z-axis was considered. Therefore, the first task was to modify the code to allow for flexible well orientation; that is, wells can be parallel to the x or y axis, whereas vertical wells are parallel to the z axis. The second major modification involved incorporating Babu *et al.'s* (*SPERE*, Aug. 1991, 324-328) well model into the simulator. The coding of these modifications is near completion. Validation of the horizontal well model will commence in the coming quarter.

Two papers related to phase behavior simulation are nearing completion. One paper will outline an application of an optimization technique for phase equilibrium computations. The other paper will provide a method for the calculation of the specific gravity associated with the characterization of the heavier components of crude oil. These two papers will be presented at the 1995 AIChE Spring National Meeting to be held in Houston, March 19-23.

TASK 3 - LOW IFT PROCESSES AND GAS INJECTION IN FRACTURED RESERVOIRS

We are continuing our research in two primary areas: 1) understanding the fundamentals of low interfacial tension behavior via theory and experiment and 2) modeling low IFT gravity drainage for application of gas injection in fractured reservoirs.

We have completed our literature survey of all the reservoir fluid IFT measurements available. Our survey indicated, with strong evidence, that the scaling exponent used in parachor calculations should not be used as an adjustable parameter. Thus, based on fundamental critical scaling and past measurements of density difference and IFT for pure components, we have recalculated parachors of all pure components (if sufficient data were available). Since the parachor is generally a linear function of molecular weight, we calculated the "equivalent parachor" for the equivalent fractions that are present in crude oil. We then compared our method with other versions of the parachor method found in the literature. It was found that our method better predicts existing gas/crude oil low IFT systems.

We believe that we understand gas-oil IFT calculations quite well now, although we need to use our pendant drop apparatus to verify calculation methodology. At that point, we will begin to research crude oil/brine and gas/brine IFT's at reservoir conditions. This work will lead to a better understanding of the three IFT's that are significant in three-phase flow.

Status of Pendant Drop Apparatus

The construction of the system is complete. We are able to circulate fluids through the density meter and form drops in a variety of needle bore sizes. Thus, we are confident that we will be able to measure ultra-low IFT systems since we have the smallest needle bore available. This coming quarter will be devoted to completion of the video imaging facilities. We are currently testing digital cameras, frame grabbers and imaging software in order to maximize our drop resolution and improve IFT measurements.

Low IFT Gravity Drainage

We have completed our system to measure free-fall gravity drainage in long reservoir whole cores at reservoir conditions. We ran our first test in Berea sandstone with a permeability of 500 md. The core was saturated with reservoir brine, flushed with West Texas crude to connate brine and allowed to age for two weeks. The core was transferred from our Hassler cell (with overburden) into a free-fall gravity drainage cell, which was mounted vertically. CO_2 was circulated through the cell at near the minimum miscibility pressure of the oil. Recovery of oil by gravity drainage was measured as a function of time, as shown in Figure 2.

We have also been investigating the process from a theoretical viewpoint. We have developed an analytical model for gravity drainage that better describes existing data. The data is scarce, though, and much more experimental work is necessary to understand the complicated exchange mechanism that occurs in nonequilibrium gravity drainage such as swelling, vaporization, low IFT development, and varying capillary pressure as the IFT's are reduced. The upcoming quarter will be devoted to improvement of our model and measuring reservoir condition CO_2 gravity drainage in low permeability reservoir rocks representative of fractured reservoirs.

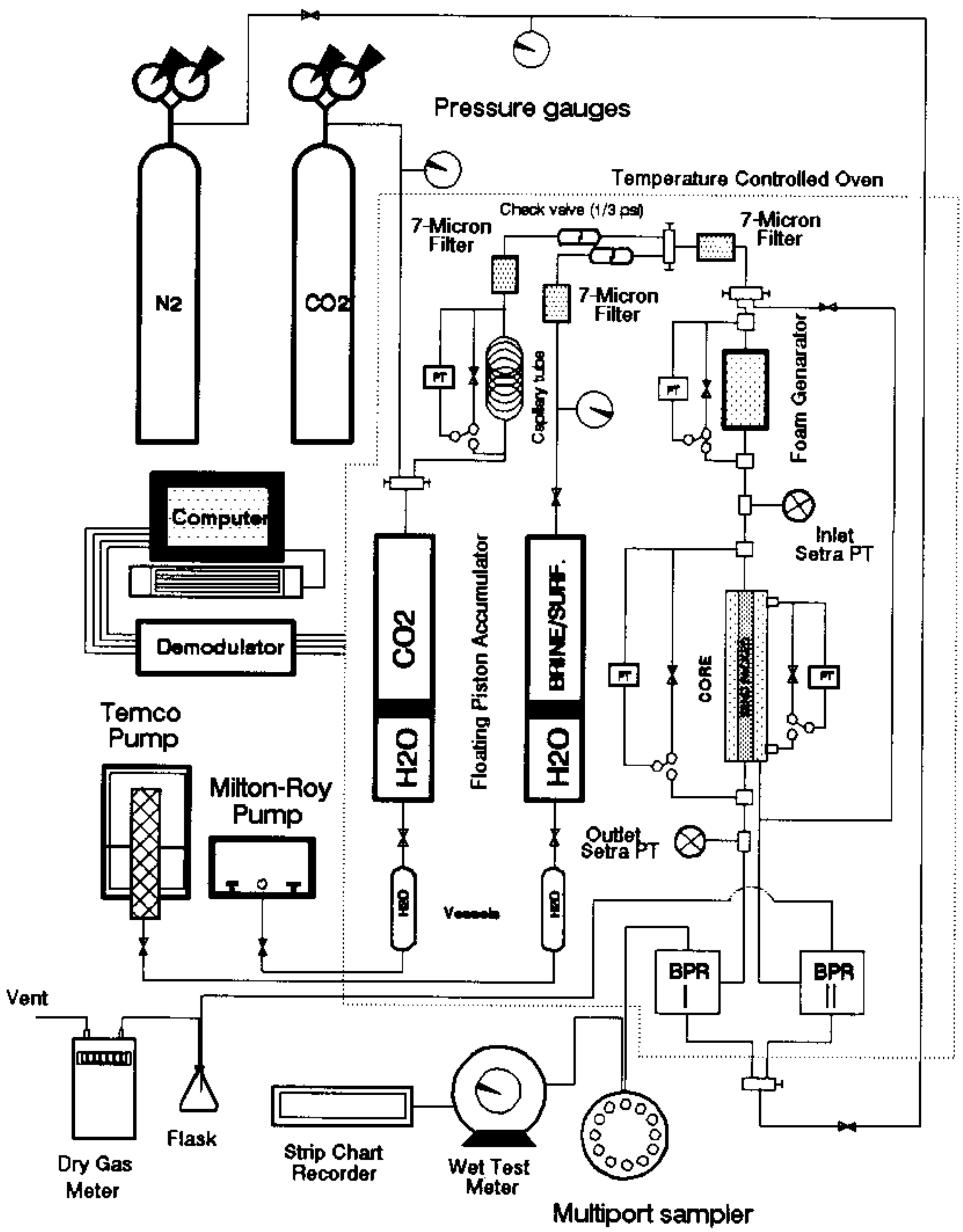

Fig. 1 Schematic diagram of the experimental aparatus

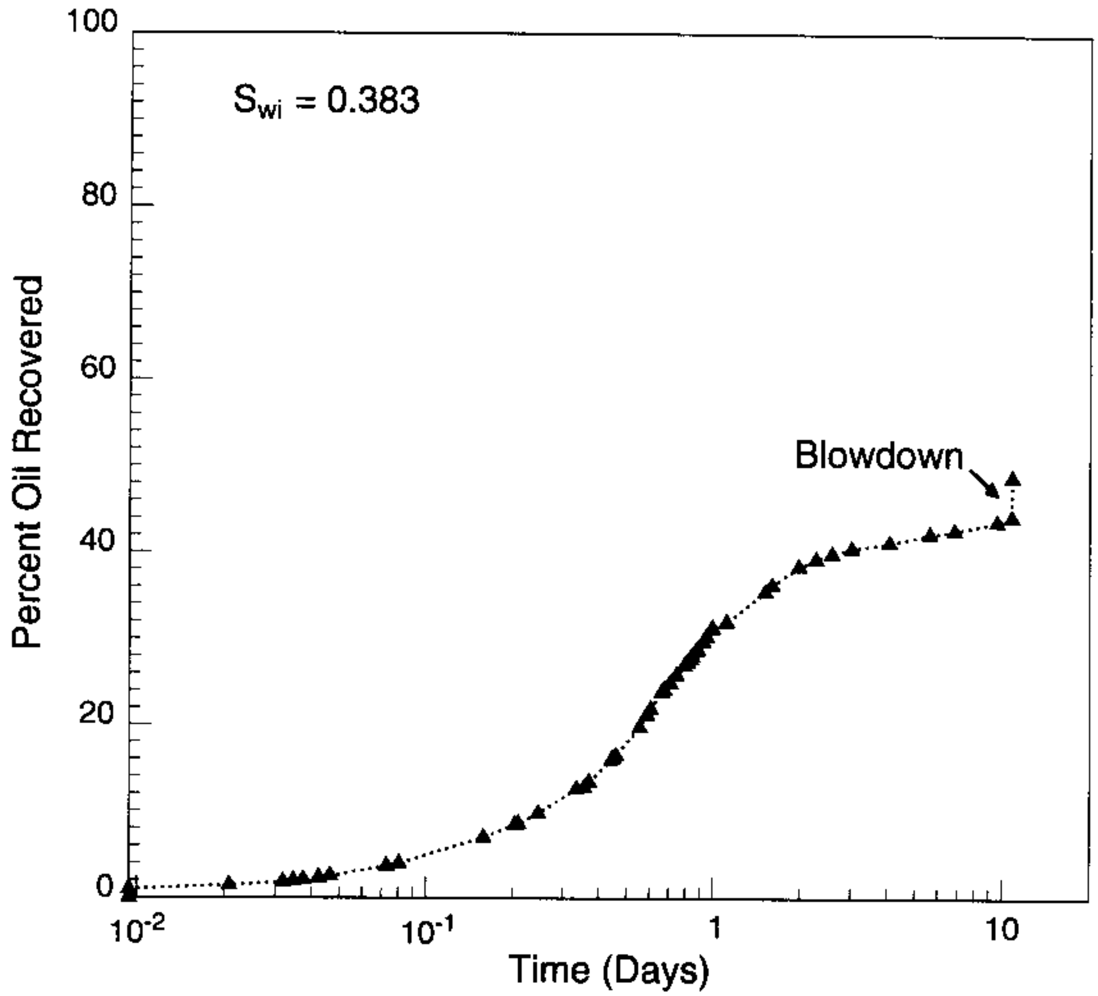

Fig. 2: CO_2 Gravity Drainage in Berea with Spraberry STO.